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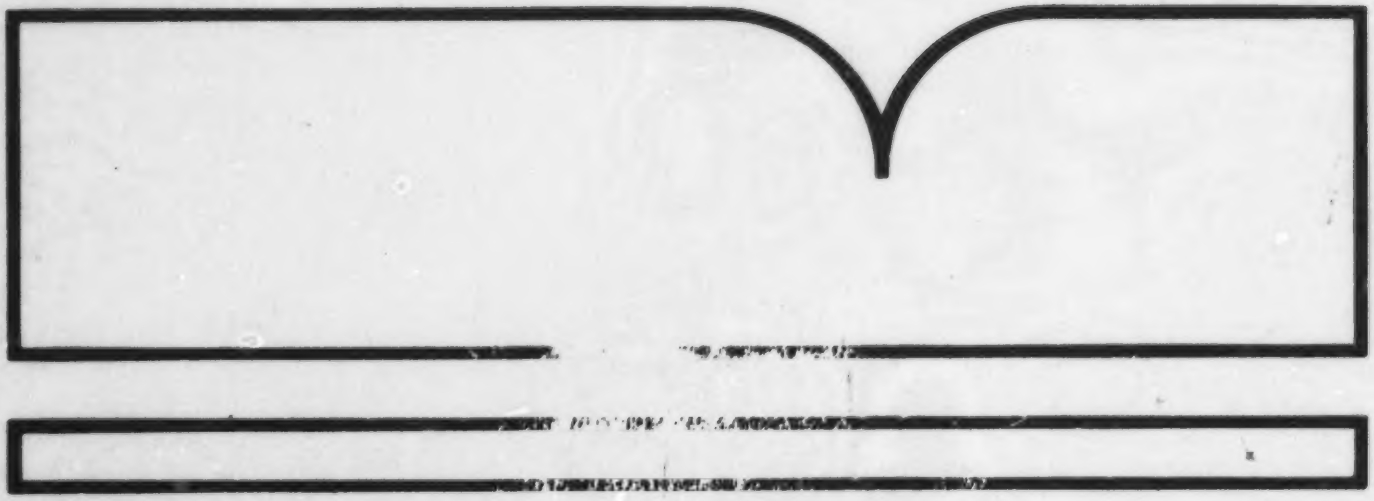

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16. ABSTRACT

A review of the 1982 world literature was conducted on the effects of pollution on freshwater fish and amphibians. This review contained 378 references and included papers on water quality such as dissolved gases and pH; chemical pollutants such as insecticides, herbicides, piscicides and anesthetics; inorganics, organics and industrial and municipal effluents including chlorine and wastewater and pulp and paper. Papers from reviews and symposia and those dealing with physical factors were also included.

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Effects of pollution on freshwater fish and amphibians

Quentin H. Pickering, Evelyn P. Hunt, Gary L. Phipps, Thomas H. Roush, Wesley E. Smith, Diane L. Spehar, Charles E. Stephan, Danny K. Tanner

Alabaster reviewed data available on joint action of mixtures to aquatic organisms.[1] A study using 5 mixtures of 8 pollutants and 1 mixture of 24 pollutants found the toxicities of the mixtures to the guppy (*Poecilia reticulata*) were near concentration addition.[2] In a review of the effects of radiation and

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Table 1—Effects of pollutants on freshwater fish and amphibians.[a]

Pollutant	Type of information
Acephate	Decreased enzyme activity in rainbow trout (*Salmo gairdneri*).[10]
Acetone	Affected growth of lake trout (*Salvelinus namaycush*) fry and uptake of PCBs.[11]
Acid mine drainage	Degraded fish in several West Virginia streams.[12] Downstream fish communities were depressed.[13]
Acrolein	96-h LC50[b] = 0.08 mg/L for rainbow trout and 0.07 mg/L for bluegill (*Lepomis macrochirus*).[14]
Acrylamide	14-d LC50 for guppy (*Poecilia reticulata* = *Lebistes reticulatus*) = 490 μmol/L.[2]
Acrylonitrile	96-h LC50 for zebrafish (*Brachydanio rerio*) = 25 mg/L; 48-h LC50 for golden orfe (*Leuciscus idus*) = 13 to 28 mg/L.[15]
Activated sludge	192-h LC50 for common carp (*Cyprinus carpio*) > 1%; caused adverse effects when added to feed.[16]
Aflatoxin	Caused carcinomas in rainbow trout.[17]
Aldrin	0.1 mg/L caused biochemical changes in *Clarius batrachus*.[18] 96-h LC50 for *Heteropneustes fossilis* = 0.175 mg/L; metabolic changes.[19] Inhibited ovarian activity of *Heteropneustes fossilis*.[20] Affected enzymes in brown trout (*Salmo trutta*) and carp.[21] 96-h LC50 for *Heteropneustes fossilis* = 0.175 mg/L; mixture with formothion.[22] 96-h LC50 for *Saccobranchus fossilis* = 0.4470 mg/L.[23] Uptake by guppy.[24]
Allyl alcohol	14-d LC50 for guppy = 14 μmol/L.[2]
Allylamine	96-h LC50 for zebrafish = 22.1 mg/L; 48-h LC50 for golden orfe = 61 to 76 mg/L.[15]
Aluminum	Chronic toxicity to white sucker (*Catostomus commersoni*) and brook trout (*Salvelinus fontinalis*) at pH = 4.2 to 5.6.[25] Effect of hardness on acute toxicity to brook trout; histopathology.[26] 28-d LC50 for rainbow trout = 560 μg/L.[27]
Americium	Concentrations in bluegill and largemouth bass (*Micropterus salmoides*).[28]
Aminex 500	Toxicity to carp, guppy, and rainbow trout.[29]
Aminocarb (Matacil)	96-h LC50 for rainbow trout = 0.36 to 29.1 mg/L for various formulations; BCF[c] = 1.7 to 3.3.[30]
Ammonia	Altered liver lysosomal activity of rainbow trout.[31] Effect of pH on acute toxicity to rainbow trout and fathead minnow (*Pimephales promelas*).[32] Effect of pH on 24-h LC50 for eel (*Anguilla japonica*); concentrations > 0.034 mg/L reduced growth of eel.[33] Effects on blood of *Heteropneustes fossilis*.[34] 96-h LC50 for rainbow trout = 0.16 to 0.49 mg/L; 72-d LC50 = 0.056 mg/L.[35] Toxicity depended on pH, temperature, and alkalinity.[36]
Amyl alcohol	96-h LC50 for zebrafish = 530 mg/L; 48-h LC50 for golden orfe = 479 to 492 mg/L.[15] Anaesthetic effect on rainbow trout prolonged by increased carbohydrate.[37]
Aniline	7-d LC50 for rainbow trout = 8.2 mg/L.[38] 96-h LC50 for zebrafish = 32 to 33 mg/L; 48-h LC50 for golden orfe = 61 to 78 mg/L.[15]
Anisole	96-h LC50 for zebrafish = >1000 mg/L; 48-h LC50 for golden orfe = 120 to 149 mg/L.[15]
Antimony	28-d LC50 for rainbow trout = 660 μg/L.[27]
Arsenic	Concentrations in bluegill and fathead minnow = 0.08 to 4.8 mg/kg.[39] Concentrations in five Canadian species.[40] Concentrations in four southwestern species.[41] Concentrations in wild striped bass (*Morone saxatilis*) and relation to abnormalities.[8] Review of toxicity and bioaccumulation.[42]
Arsenic (III)	Preexposure increased depuration by rainbow trout.[43] 28-d LC50 for rainbow trout = 550 μg/L.[27]
Arsenic (V)	15 mg/L caused histopathological changes in liver of channel catfish (*Ictalurus punctatus*) after 6 months.[44]
Ascorbic acid	Affected toxicity of mercury to goldfish (*Carassius auratus*).[45] Decreased effects of copper on rainbow trout.[46] Not related to deformities in zebrafish.[47]
Bacteriological contamination	Resulted in microorganisms in intestines of fish.[48]
Barium	28-d LC50 for rainbow trout = 42.7 mg/L.[27]
Bayer 73 (lampricide)	Potential adverse and beneficial effects on lake trout.[49]
Benz(a)acridine	Bioconcentration and metabolism by fathead minnow.[50]
Benzene	96-h LC50 = 5.3 mg/L for rainbow trout and 15.1 mg/L for fathead minnow.[51]

(Table 1 Continued)

Table 1—(Continued)

Pollutant	Type of information
Benzocaine	Time necessary to affect *Poecilia shenops* increased by Pluronic F-68.[52]
Benzonitrile	96-h LC50 for zebrafish = 130 mg/L; 48-h LC50 for golden orfe = 54 to 97 mg/L.[15]
Benzopyrene	Produced mutants in bluegill cell cultures.[53] Metabolized to proximate carcinogen by cell lines from three species.[54]
Benzylchloride	96-h LC50 for zebrafish = 4 mg/L; 48-h LC50 for golden orfe = 3 to 16 mg/L.[15]
s-Benzyl-o,o-diisopropyl phosphorothioate (IBP)	BCF with *Pseudorasbora parva* = 4.[55]
Beryllium	28-d LC50 for rainbow trout = 380 μg/L.[27]
Birlane 24EC (Chlorfenvinphos)	Acute toxicity to Czechoslovakian fish.[56]
Bolero 8EC (Benthiocarb)	96-h LC50 for three species = 1.2 to 2.3 mg/L; 5-d BCF with four species = 80 to 47.[57]
Boron	Concentrations in five Canadian species.[40] 28-d LC50 for rainbow trout = 70.1 mg/L.[27]
Bromide	96-h LC50 for fathead minnow = 16 500 mg/L.[58]
Butyl acetate	96-h LC50 for zebrafish = 62 mg/L; 48-h LC50 for golden orfe = 71 to 141 mg/L.[15]
2-sec-Butylphenyl methylcarbamate (BPMC)	BCF with *Pseudorasbora parva* = 26.[55]
Cadmium	Accumulation from water and food and depuration by guppy.[59] Biochemical changes in rainbow trout after 6 months; mixtures with chromium and nickel.[60] Biochemical changes in *Channa punctatus*.[61] Concentrations and abnormalities in wild striped bass.[8] Concentrations in four British species.[62] Concentrations in two Hungarian species.[63] Concentrations in live and dead *Scardinius erythrophtalmus*.[64] Concentrations in fish from contaminated and uncontaminated areas.[65] Decreased glucose transport in *Channa punctatus*.[66] Dietary effects on blood and skeleton of rainbow trout.[67] Effects of EDTA on depuration by common carp.[68] Effects on immune response of brown trout.[69] Effects on glycogen levels in *Heteropneustes fossilis*.[70] Effects on fish.[71] Effects on blood and head kidney of brown bullhead (*Ictalurus nebulosus*).[72] Acute, chronic, and bioconcentration tests with four species.[73] 96-h LC50 for chinook salmon (*Oncorhynchus tshawytscha*) = 1.1 μg/L; mixtures with copper and zinc.[74]

Pollutant	Type of information
Cadmium (Continued)	96-h LC50 for bluegill = 2.3 to 2.5 mg/L; 50 to 115 μg/L increased ventilation frequency and cough rate.[75] 28-d LC50 for rainbow trout = 140 μg/L; mixture with mercury.[27] Acute toxicity to, and uptake by, *Oryzias latipes* eggs.[76] Increased hepatoprotein in rainbow trout.[77] Inhibition of catalase, alone and in mixtures of metals.[78] 0.1 mg/L reduced survival and growth of young rainbow trout.[79] 10 mg/kg (IP^a) altered hepatocytes in *Pimelodus maculatus*.[80] LC50 for rainbow trout = 16 to 17 μg/L; chronic physiological and biochemical effects.[81] 96-h LC50 for zebrafish = 3.5 to 11.2 mg/L; $MATC^a$ = 1 to 10 μg/L.[82] Concentrations in Tennessee striped bass.[83] 8.2 μg/L killed alevins of Atlantic salmon (*Salmo salar*); 0.47 μg/L inhibited growth; uptake by eggs and alevins.[84] Concentrations in four cyprinids.[85] Concentrations in four German species.[86] Uptake and depuration by rainbow trout, alone and in mixtures with nickel and chromium.[87] Uptake from food and water and lethality to guppy.[88] Effect of urban runoff on concentrations in three species.[89]
Caffeine	Affected schooling of jewelfish (*Hemichromis bimaculatus*).[90]
Calcium	Concentrations in nine Canadian species.[91] Increase survival of young brown trout at pH = 4.5.[92] Uptake from food by common carp.[93] Effects on blood of *Heteropneustes fossilis*.[94] Increased survival of various species at low pH.[94]
Cantharidin	14-d LC50 for guppy = 0.65 μmol/L.[2]
Carbaryl (Sevin)	BCF with *Pseudorasbora parva* = 9.[55] 2.5 mg/L increased metabolic rate in *Macropodus cupanus*.[95] LC50 for four species = 2.4 to 6.4 mg/L.[96] 96-h LC50 for *Saccobranchus fossilis* = 20 mg/L.[23] Uptake by guppy.[24] 48-h LC50 = 3.74 mg/L for *Aplocheilus lineatus* and 13.9 mg/L for *Macropodus cupanus*.[97] 96-h LC50 = 27 mg/L for *Anabus scandens* and 50 mg/L for *Heteropneustes fossilis*.[98] Reduced tissue respiration in *Sarotherodon mossambicus*.[99]
Carbofuran	0.5 mg/L caused biochemical changes in *Clarias batrachus*.[100] Affected enzymes in *Mystus vittatus*.[101] 462 μg/L inhibited enzymes in *Channa punctatus*.[102] 96-h LC50 for *Saccobranchus fossilis* = 0.547 mg/L.[23]
Carbon	Review of available bioaccumulation factors.[103]
Carbon dioxide	Useful anesthetic for common carp.[104]
Cesium	Concentrations in nine Canadian species.[91] 28-d LC50 for rainbow trout = 181 mg/L.[27] Review of available bioaccumulation factors.[103]

Table 1—(Continued)

Pollutant	Type of Information
Chicken manure	96-h LC50 for common carp = 0.29%; caused adverse effects when added to feed.[16]
Chloralkylene 12	Did not induce mixed function oxidase in brook trout.[105]
Chlordane	96-h LC50 for *Saccobranchus fossilis* = 0.42 mg/L.[23] Concentrations in wild striped bass and relation to abnormalities.[8] Concentration in various Finnish species.[106] Concentration in lake whitefish (*Coregonus clupeaformis*) decreased in two Great Lakes.[107]
Chloride	Effect on toxicity of nitrite to bluegill.[108]
Chlorinated wastewater effluent	Downstream fish showed increased mutagenic activity.[109]
Chlorine	Affected toxicity of nickel to rainbow trout.[110] Effects on striped bass eggs in fresh and salt water.[111]
Chlorisophos	Acute toxicity to Czechoslovakian species.[56] LC50 = 15 μL/L for common carp and 4 μL/L for guppy.[112]
Chlornitrofen	BCF with *Pseudorasbora parva* = 1109.[55]
Chlorobenzenes	Concentrations in lake trout (*Salvelinus namaycush*) and rainbow trout in Great Lakes.[113]
4-Chloro-4'-isopropylbiphenyl	Uptake and metabolism by common carp.[114]
4-Chlorophenol	96-h LC50 for guppy = 49 to 70 μmol/L at pH 5 to 8.[115]
Chromium	Concentrations in live and dead *Scardinius erythrophtalmus*.[64] Concentrations in Yugoslavian species.[116] Increased glucose transport in *Channa punctatus*.[66] Concentrations in four German species.[86] Concentrations in four cyprinids.[65] Review of toxicity and bioaccumulation.[117] Effect of urban runoff on concentrations in three species.[89]
Chromium (III)	Acute toxicity to common carp and *Aristichthis nobilis*.[118] Complexing agents reduced acute toxicity to and uptake by common carp.[119] Effects on growth of rainbow trout.[120]
Chromium (VI)	Biochemical changes in rainbow trout after 6 months; mixtures with nickel and cadmium.[60] Biochemical changes in *Channa punctatus* after 30 d.[121] Effect on immune response of channel catfish.[122] Effect of pH on acute changes in respiration and physiology of rainbow trout.[123] Effect of pH on transfer in perfused gills of rainbow trout.[124] Effect of pH on chronic toxicity to rainbow trout.[125] Effect of pH on uptake and depuration by rainbow trout.[126]
Chromium (VI) (Continued)	Effect of pH on acute toxicity to rainbow trout.[127] Inhibition of catalase, alone and in mixtures of metals.[78] 96-h LC50 for *Mystus vittatus* = 200 mg/L; mixtures with zinc and nickel.[128] 28-d LC50 for rainbow trout = 190 μg/L.[27] Uptake and effects of chelating agents on elimination by *Notopterus notopterus*.[129] Uptake and depuration by rainbow trout, alone and in mixtures with cadmium and nickel.[87]
Citric acid	Reduced toxicity of copper to guppy.[130]
Coal synfuel blends	Test methodology affected lethality to fathead minnow.[131]
Cobalt	Concentration in Yugoslavian species.[116] Effect on blood cells and eggs of three species.[132] 28-d LC50 for rainbow trout = 490 μg/L.[27] Review of available bioaccumulation factors.[103]
Copper	Acute toxicity to rainbow trout was not affected by PCBs.[133] Avoidance threshold for rainbow trout = 6.4 μg/L.[134] Time and concentration affected binding by protein fractions in liver of coho salmon (*Oncorhynchus kisutch*).[135] Complexing agents reduced chronic toxicity to and uptake by common carp.[136] Complexed by mucus from rainbow trout.[137] Concentrations in two Welsh species.[138] Concentrations in nine Canadian species.[91] Concentrations in two Hungarian species.[63] Concentrations in live and dead *Scardinius erythrophtalmus*.[64] Concentrations in five Canadian species.[40] Effects on blood cells and eggs of three species.[132] Effects of dietary mixtures with zinc on rainbow trout.[139] Effects on glycogen levels in *Heteropneustes fossilis*.[70] Effect of diet on sensitivity of rainbow trout.[140] Effect on susceptibility of channel catfish to infections.[141] Effects on rainbow trout decreased by ascorbic acid.[46] Effects on blood of three species.[142] Effects of complexing agents on acute toxicity to guppy.[130] Effects of mercury and zinc on acute toxicity to *Channa marulius*.[143] Effects of nickel and zinc on acute toxicity to guppy.[144] Inhibition of catalase, alone and in mixtures of metals.[78] 96-h LC50 for chinook salmon = 32 μg/L; mixtures with cadmium and zinc.[74] 96-h LC50 for rainbow trout eyed eggs = 400 μg/L.[145] 96-h LC50 for *Ophiocephalus punctatus* = 607 μg/L.[146] 96-h LC50 for *Mystus bleekeri* = 850 μg/L; histopathology.[147] 28-d LC50 for rainbow trout = 110 μg/L; mixture with mercury.[27] 70 μg/L reduced growth and caused uptake and acclimation of coho salmon.[148] Relationship of sex and size on survival time of guppy.[149] Probable cause of toxicity to *Chondrostoma* sp. in Venda Nove Reservoir.[150] Concentrations in four German species.[86] Concentrations in *Leuciscus cephalus* and *Rutilus rutilus*.[151] Uptake from food by common carp.[93] Uptake and acclimation by rainbow trout.[77] Effect of urban runoff on concentrations in three species.[89]

(Table 1 Continued)

Table 1—(Continued)

Pollutant	Type of information
Copper (organic and inorganic)	Acute lethality and pathological effects.[152]
	Histopathological effects on common carp and rainbow trout.[153]
Copper sulfate complex	96-h LC50 for zebrafish = 160 mg/L; 48-h LC50 for golden orfe = 160 mg/L.[15]
m-Cresol	96-h LC50 for zebrafish = 15.9 mg/L; 48-h LC50 for golden orfe = 17 to 19 mg/L.[15]
o-Cresol	96-h LC50 for zebrafish = 24 mg/L; 48-h LC50 for golden orfe = 10 mg/L.[15]
Crude oil	Induced mixed function oxidase in American eel (*Anguilla rostrata*).[154]
Cyanide	0.01 mg/L reduced fecundity of rainbow trout.[155]
Cyclohexylamine	96-h LC50 for zebrafish = 470 mg/L; 48-h LC50 for golden orfe = 58 to 95 mg/L.[15]
Cyclopropene fatty acids	Decreased enzyme activity in rainbow trout.[156]
Cypermethrin	96-h LC50 for five species = 0.4 to 2.2 μg/L.[157]
	Comparison of pond study and laboratory tests.[158]
	No detectable concentrations in *Scardinius erythrophthalmus* or *Carassis carassius* because of spray drift.[159]
Cytox 2410 (VBT)	96-h LC50 for rainbow trout = 0.57 mg/L.[14]
2,4-D, butoxyethanol ester	Biochemical effects on sockeye salmon (*Oncorhynchus nerka*).[160]
2,4-D, butyl ester	96-h LC50 for cutthroat trout (*Salmo clarki*) = 0.78 mg/L.[161]
2,4-D, DMA	Acute toxicity to rainbow trout was increased by PCBs.[133]
2,4-D, isooctyl ester	96-h LC50 for cutthroat trout > 50 mg/L.[161]
2,4-D, propylene glycol ether ester	96-h LC50 for cutthroat trout = 0.77 mg/L.[161]
DDC (chelating agent)	Increased depuration of metals by *Notopterus notopterus*.[129]
DDD	Concentrations and abnormalities in wild striped bass.[8]
	Cooking reduced concentration in common carp fillets.[162]
	Concentrations in four Canadian species.[40]
	Relationship of concentrations in two Italian species to lipids, length, and concentration in water.[163]
DDE	Concentrations and abnormalities in wild striped bass.[8]
	Concentrations in four Canadian species.[40]
	Cooking reduced concentration in common carp fillets.[162]
DDE (Continued)	Relationship of concentrations in two Italian species to lipids, length, and concentration in water.[163]
	Concentrations in common carp from Lake Huron.[164]
	Size-specific mortality of lake trout fry.[165]
	Concentration in lake whitefish increased in two Great Lakes.[107]
DDT	BCF with *Rutilus rutilus* = 1 070 000.[166]
	Concentrations and abnormalities in wild striped bass.[8]
	Concentrations in various Finnish species.[106]
	Concentrations in two African species.[167]
	Concentrations in four Canadian species.[40]
	Concentrations in seven Iowa species.[168]
	Concentrations averaged 5.1 μg/L in water and 61 μg/kg in *Tilapia* sp.[169]
	48-h LC50 for *Aplocheilus lineatus* = 0.122 mg/L; for *Macropodus cupanus* = 2.28 mg/L.[97]
	96-h LC50 for common carp = 0.151 mg/L.[170]
	Relationship of concentrations in two Italian species to lipids, length, and concentration in water.[163]
	Concentrations in common carp from Lake Huron.[164]
	Concentration in lake whitefish decreased in two Great Lakes.[107]
	Uptake by guppy.[24]
DDTA (chelating agent)	Increased depuration of metals by *Notopterus notopterus*.[129]
DTPA (chelating agent)	Increased depuration of metals by *Notopterus notopterus*.[129]
	Effect on depuration of cadmium by common carp.[68]
Decamethrin	0.063 mg/L killed *Astyanax fasciatus* in 5 h.[171]
Dehydroabietic acid	BCF with rainbow trout = 80.[172]
	1.55 mg/L caused morphological changes in rainbow trout in 96 h.[173]
Dialkyl dithiolanylidenemalonates	BCFs for nine analogs with *Oryzias latipes* = 0.68 to 102.[174]
Diazinon	BCF with *Pseudorasbora parva* = 152.[55]
	Effects of acute and chronic exposures on enzymes in *Channa punctatus*.[175]
	Physiological effects on *Heteropneustes fossilis*.[176]
	96-h LC50 for *Channa punctatus* = 3.1 mg/L; 0.31 mg/L inhibited enzymes in 30 d.[177]
	96-h LC50 for *Saccobranchus fossilis* = 2.27 mg/L.[23]
	96-h LC50 for fathead minnow = 6.90 mg/L.[178]
2,6-Dibromo-4-nitrophenol	96-h LC50 for guppy = 5.7 to 38.7 μmol/L at pH 6 to 8.[115]
Dicamba	96-h LC50 for cutthroat trout > 50 mg/L.[161]
Dichlorobenzene	Review of toxicity and bioaccumulation.[179]
	24-h LC50 for rainbow trout = 1.2 mg/L; BCF varied with age.[180]
	Concentrations in lake and rainbow trout in Great Lakes.[113]

Table 1—(Continued)

Pollutant	Type of information
4,5-Dichlorocatechol	96-h LC50 for rainbow trout = 0.5 to 1.0 mg/L.[181]
1,2-Dichloroethane	Estimated MATC for fathead minnow = 29 to 59 mg/L.[182]
2,6-Dichlorohydroquinone	96-h LC50 for rainbow trout > 0.5 mg/L.[181]
3,5-Dichloro-4'-isopropylbiphenyl	Uptake and metabolism by common carp.[113]
2,4-Dichloro-p-nitrobiphenyl ether	120-h BCF with goldfish = 1200.[183]
2,4-Dichlorophenol	96-h LC50 for zebrafish = 3.9 mg/L; 48-h LC50 for golden orfe = 5 mg/L.[15] 42 μg/L decreased survival of fathead minnow.[184]
1,2-Dichloropropane	Estimated MATC for fathead minnow = 6 to 11 mg/L.[182]
1,3-Dichloropropane	Estimated MATC for fathead minnow = 8 to 16 mg/L.[182]
2,3-Dichloropropane	14-d LC50 for guppy = 11 μmol/L.[2]
Dichlorovos	Effects on enzymes in *Mystus vittatus*.[101] 96-h LC50 for *Saccobranchus fossilis* = 6.61 mg/L.[23]
Dieldrin	Concentrations in channel catfish dropped from 75 to 46 μg/kg over 7 years.[185] BCF was proportional to oil content in Iowa species.[186] BCF with *Pseudorasbora parva* = 4430.[55] Concentrations in two African species.[167] Concentrations in seven Iowa species.[168] Concentrations in common carp from Lake Huron.[164] Concentrations in lake whitefish decreased in two Great Lakes.[107] 14-d LC50 for guppy = 0.017 μmol/L.[2]
Diflubenzuron	45 μg/L did not affect 30-d survival or growth of two species.[187]
2-Digeranylamino-ethanol	Acute toxicity to rainbow trout was not affected by PCBs.[133]
Dimethoate	96-h LC50 for *Saccobranchus fossilis* = 4.57 mg/L.[23]
7,12-Dimethylbenz(a)anthracene	5 mg/L induced liver neoplasms in two *Poeciliopsis* species.[188]
Dimethylformamide	Did not affect acute toxicity of tetrachloroethylene to rainbow trout.[189]
2,4-Dimethylphenol	61.3 μg/L decreased growth of fathead minnow.[184]
1,3-Dinitrobenzene	14-d LC50 for guppy = 56 μmol/L.[2]
2,4-Dinitro-6-sec-butylphenol (Dinoseb)	96-h LC50 for guppy = 0.44 to 4.10 μmol/L at pH 6 to 8.[115]
2,4-Dinitrophenol	Effects of mixtures with phenol and pentachlorophenol on phosphatases of *Notopterus notopterus*.[190]
Dipterex (Trichlorfon)	96-h LC50 for *Saccobranchus fossilis* = 31 mg/L.[23]
Disulfiram	14-d LC50 for guppy = 0.022 μmol/L.[2]
Dodecylcyclohexane	Uptake and depuration by rainbow trout.[191]
Dodecyl octa (oxyethylene) ether	BCF with common carp is concentration dependent.[192]
DOW EC-7 (88% pentachlorophenol)	96-h LC50 = 0.20 mg/L for rainbow trout and 0.86 mg/L for bluegill.[14]
Dursban (Chlorpyrifos)	96-h LC50 for fathead minnow = 0.12 to 0.14 mg/L.[178]
EDTA (chelating agent)	Effect on depuration of cadmium by common carp.[68] Increased depuration of metals by *Notopterus notopterus*.[129] Reduced toxicity of copper to guppy.[130]
β-Endorphin	Increased schooling behavior of goldfish.[193]
Endosulfan	Concentrations in two African species.[167] 2 μg/L decreased glucose absorption in *Channa punctatus*.[194] Aerial spraying caused mortality and accumulation.[195] Affected carbohydrate metabolism in *Heteropneustes fossilis*.[196] 24-h LC50 for five African species = 1.2 to 7.4 μg/L; spraying killed some fish.[197] 96-h LC50 for *Heteropneustes fossilis* = 0.0020 mg/L.[22] 96-h LC50 for three species = 1.1 to 2.2 μg/L.[198] Review of toxicity and bioconcentration.[199] Spraying for tsetse fly killed fish.[200] Spraying caused liver and brain damage to various species.[201] 96-h LC50 for *Cirrhinus mrigala* = 1.3 μg/L.[202] Caused biochemical changes in *Channa punctata*.[203]
Endosulfan A	96-h LC50 for *Cirrhinus mrigala* = 0.6 μg/L.[202] 14-d LC50 for guppy = 0.0018 μmol/L.[2] Caused biochemical changes in *Channa punctata*.[203]
Endosulfan B	96-h LC50 for *Cirrhinus mrigala* = 8.8 μg/L.[202] Caused biochemical changes in *Channa punctata*.[203]
Endrin	Effects on blood of *Heteropneustes fossilis*.[34] Brook trout gills removed 80% from water.[204] Concentration in lake whitefish decreased in two Great Lakes.[107]
Epichlorohydrin	96-h LC50 for zebrafish = 30.5 mg/L; 48-h LC50 for golden orfe = 24 mg/L.[15]
Ethyl acrylate	14-d LC50 for guppy = 7.4 μmol/L.[2]

(Table 1 Continued)

Table 1—(Continued)

Pollutant	Type of information
Ethyl glycol acetate	96-h LC50 for zebrafish = 98 mg/L; 48-h LC50 for golden orfe = 107 to 141 mg/L.[15]
o-Ethyl-o-4-nitrophenyl phenylphosphonothioate (EPN)	BCF with *Pseudorasbora parva* = 2346.[55]
Etomidate	Potent and safe anesthetic for fish.[205] 24-h LC50 for several species = 0.6 to 2.7 mg/L; useful anesthetic.[206]
Fenitrothion (Sumithion)	BCF with *Pseudorasbora parva* = 246.[55] 96-h LC50 for *Saccobranchus fossilis* = 12 to 55 mg/L.[23] 48-h LC50 for *Sarotherodon mossambicus* = 6 mg/L; enzyme inhibition.[207] Reduced tissue respiration in *Sarotherodon mossambicus*.[99]
Fention	48-h LC50 = 0.49 mg/L for *Aplocheilus lineatus* and 6.3 mg/L for *Macropodus cupanus*.[208]
Firemaster BP-6	Induced mixed function oxidase in brook trout.[105]
Flumequin	Uptake and depuration by rainbow trout.[209]
Fluridone	Uptake and depuration by rainbow trout.[210]
Fluoroacetamide	14-d LC50 for guppy = 760 μmol/L.[2]
Formaldehyde	96-h LC50 for zebrafish = 41 mg/L; 48-h LC50 for golden orfe = 15 to 32.5 mg/L.[15]
Formalin	Acute toxicity to rainbow trout was not affected by PCBs.[133]
Formothion	10.4 mg/L affected physiology of *Heteropneustes fossilis*.[211] 96-h LC50 for *Heteropneustes fossilis* = 13 mg/L; mixture with aldrin.[22] 96-h LC50 for *Saccobranchus fossilis* = 143 mg/L.[23]
Furanace (Nifurpirinol)	Acute toxicity to rainbow trout was not affected by PCBs.[133]
Galinex Special	More toxic to guppy than to common carp or rainbow trout.[29]
Gallium	28-d LC50 for rainbow trout = 3.51 mg/L.[27]
Germanium	28-d LC50 for rainbow trout = 50 μg/L.[27]
Giv Guard BNS	96-h LC50 = 0.11 mg/L for rainbow trout and bluegill.[14]
Glycine	Reduced toxicity of copper to guppy.[130]
Halowax 2141 (polychlorinated naphthalenes)	Did not induce mixed function oxidase in brook trout.[105]
Heavy metals	Populations and tissue concentrations indicate severe pollution of Upper Arkansas River.[212]
Heptachlor	96-h LC50 for *Saccobranchus fossilis* = 0.0924 mg/L.[23]
Heptachlor epoxide	Concentrations in seven Iowa species.[166] Concentration in lake whitefish decreased in two Great Lakes.[107]
1-Heptanol	96-h LC50 for zebrafish = 63 mg/L; 48-h LC50 for golden orfe = 29 to 41 mg/L.[15]
Hexachlorobenzene (HCB)	Concentrations in four Canadian species.[40] Did not induce mixed function oxidase in brook trout.[105] Kinetics in three salmonids.[213] Relationship of concentrations in two Italian species to lipids, length, and concentration in water.[163] Concentrations in various European species.[214] Concentration in lake whitefish decreased in two Great Lakes.[107] Concentrations in lake and rainbow trout in Great Lakes.[113]
Hexachlorobutadiene	Did not induce mixed function oxidase in brook trout.[105] Estimated MATC for fathead minnow = 6.5 to 13 μg/L.[162] Review of toxicity and bioaccumulation.[215]
Hexachlorocyclohexane (BHC, see also lindane)	BCF with *Pseudorasbora parva* = 1246.[55] Concentrations in two African species.[167] Concentrations in four Canadian species.[40] Effects on blood of *Heteropneustes fossilis*.[34] 96-h LC50 for common carp = 0.128 mg/L.[170] Concentration in lake whitefish decreased in two Great Lakes.[107] Relationship of concentrations in two Italian species to lipids, length, and concentration in water.[163] 96-h LC50 for *Saccobranchus fossilis* = 2.45 mg/L.[23]
Hexadrin	Inhibited ovarian activity of *Heteropneustes fossilis*.[20]
1-Hexanol	96-h LC50 for zebrafish = 144 mg/L; 48-h LC50 for golden orfe = 115 to 131 mg/L.[15]
2-Hexanol	96-h LC50 for zebrafish = 340 mg/L; 48-h LC50 for golden orfe = 287 to 332 mg/L.[15]
4-Hexylresorcinol	14-d LC50 for guppy = 5.2 μmol/L.[2]
Hydrazine	96-h LC50 for bluegill = 1.6, 1.0, and 1.2 mg/L at 10°, 15.5°, and 21°C, respectively.[216]
Hydroquinone	96-h LC50 for zebrafish = 0.17 mg/L; 48-h LC50 for golden orfe = 0.15 to 0.16 mg/L.[15]
8-Hydroxyquinoline	14-d LC50 for guppy = 0.10 μmol/L.[2]

Table 1—(Continued)

Pollutant	Type of information
Iodine	
	24-h LC50 for channel catfish = 0.44 mg/L.[217]
	Review of available bioaccumulation factors.[103]
Iron	
	1.3 mg/L killed rainbow trout larvae.[218]
	Concentrations in Yugoslavian species.[116]
	Concentrations in two Welsh species.[138]
	Concentrations in two Hungarian species.[63]
	Concentrations in four German species.[86]
	Uptake from food by common carp.[93]
Iron (III)	
	Inhibition of catalase, alone and in mixtures of metals.[78]
Isopropylnaphthalene	
	Uptake from food and enzyme induction in brook trout.[219]
Isothioate	
	Uptake by guppy.[24]
Kepone (Chlordecone)	
	Concentrations in four species in Virginia ≥0.3 mg/kg.[220]
	Altered bone development and metabolism in fathead minnow.[221]
	96-h LC50 for three species = 35 to 514 μg/L.[222]
Kraft mill effluent	
	Affected liver of rainbow trout.[223]
LAS	
	BCF with common carp is concentration dependent.[192]
	96-h LC50 for rainbow trout = 5 mg/L.[224]
Lanthanum	
	28-d LC50 for rainbow trout = 20 μg/L.[27]
Lasso (Alachlor)	
	5 μg/L killed common carp fry in 29 days.[225]
Lead	
	Concentrations in five Canadian species.[40]
	Concentrations in fish from contaminated and uncontaminated areas.[65]
	Concentrations in four British species.[62]
	Concentrations and abnormalities in wild striped bass.[8]
	Concentrations in two Hungarian species.[63]
	Effects on blood cells and eggs of three species.[132]
	Effects on fish.[71]
	Effects on immune response of brown trout.[69]
	Effects on uptake and growth of rainbow trout and rainbow smelt (*Osmerus mordax*); neurotoxicity to rainbow trout.[226]
	28-d LC50 for rainbow trout = 220 μg/L.[27]
	100 μg/L altered size selected predation by zebrafish.[227]
	Inhibition of catalase, alone and in mixtures of metals.[78]
	Relationship to deformities in zebrafish.[47]
	Concentrations in four German species.[86]
	Review of toxicity and bioaccumulation.[228]
	Uptake from food exceeds uptake from water by guppy.[229]
	Effect of urban runoff on concentrations in three species.[89]
Leptophos	
	BCF with *Pseudorasbora parva* = 6 058.[55]
	96-h LC50 for *Saccobranchus fossilis* = 22.6 mg/L.[23]
Lethane 384	
	14-d LC50 for guppy = 5.8 μmol/L.[2]
Lidocaine	
	Time necessary to affect *Poecilia shenops* was increased by Pluronic F-68.[52]
Lindane (see also hexachlorocyclohexane)	
	Affected protein conversion in rainbow trout.[230]
	Concentrations averaged 2.1 μg/L in water and 35 μg/kg in *Tilapia* sp.[169]
	96-h LC50 for *Saccobranchus fossilis* = 0.537 mg/L.[23]
	96-h LC50 for *Colisa lalia* = 0.135 mg/L.[231]
	14-d LC50 for guppy = 0.20 μmol/L.[2]
Lindex	
	96-h LC50 for two species = 0.65 to 0.8 mg/L.[96]
Liquid manure	
	Eliminated several downstream species.[232]
Lithium	
	Effects on behavior of goldfish.[233]
	28-d LC50 for rainbow trout = 9.28 mg/L.[27]
MS-222 (Tricaine methanesulphonate)	
	Acute toxicity to rainbow trout was not affected by PCBs.[133]
	Decreased drug-metabolizing enzymes in splake (*Salvelinus fontinalis* × *Salvelinus namaycush*).[234]
	Effects, with and without nitrite, on methemoglobin in channel catfish.[235]
	Effects on three species depended on temperature, hardness, and loading.[236]
	50 mg/L elevated plasma cortisol in rainbow trout.[237]
	Anaesthetic effect on rainbow trout was not prolonged by increased carbohydrate.[37]
	Toxicity to three species reduced by pH adjustment.[238]
Magnesium	
	Uptake from food by common carp.[93]
	28-d LC50 for rainbow trout = 1355 mg/L.[27]
Malachite Green	
	Acute toxicity to rainbow trout was decreased by PCBs.[133]
Malathion (Cythion)	
	Reduced ammonia and urea in tissue of Mozambique tilapia (*Tilapia mossambica*).[239]
	48-h LC50 = 0.975 mg/L for *Aplocheilus lineatus* and 4.6 mg/L for *Macropodus cupanus*.[97]
	96-h LC50 for common carp = 2.5 mg/L.[170]
	96-h LC50 for *Saccobranchus fossilis* = 15 mg/L.[23]
	14-d LC50 for guppy = 4.0 μmol/L.[2]
	Inhibited ovarian activity of *Heteropneustes fossilis*.[20]
Malatox	
	96-h LC50 for *Saccobranchus fossilis* = 9.79 mg/L.[23]
Manganese	
	Concentrations in two Welsh species.[138]
	Concentrations in two Hungarian species.[63]
	Uptake from food by common carp.[93]
Manganese (II)	
	BCF with yellow perch (*Perca flavescens*) = 11.[240]
	Inhibition of catalase, alone and in mixtures of metals.[78]
	28-d LC50 for rainbow trout = 2.91 mg/L.[27]

(Table 1 Continued)

Table 1—(Continued)

Pollutant	Type of information
Manure slurry	Caused fish kill.[241]
Menthol	14-d LC50 for guppy = 100 μmol/L.[2]
Mercury	Concentrations in two Hungarian species.[63] Concentrations in Australian eels.[242] Concentrations in five Canadian species.[40] Distribution in liver of lake trout.[243] Effects on fish.[71] Concentrations in four German species.[86] Concentrations in nine Canadian species.[244] Concentrations in *Leuciscus cephalus* and *Rutilus rutilus*.[151] Uptake from food by common carp.[93] Effect of urban runoff on concentrations in three species, evidence for biomagnification and bioaccumulation.[89]
Mercury (organic and inorganic)	Concentrations in Canadian yellow perch.[245] Uptake and distribution in rainbow trout fed contaminated tubificids.[246]
Mercury (II)	Accumulation from water and food and depuration by guppy.[247] Biochemical effects on *Channa punctatus* after 60 d.[248] Biochemical effects of 0.3 mg/L on *Heteropneustes fossilis*.[249] Effects of ascorbic acid on acute toxicity and uptake by goldfish.[45] Effects of copper and zinc on acute toxicity to *Channa marulius*.[143] Effects on glycogen levels in *Heteropneustes fossilis*.[70] Effects on intestinal absorption of nutrients in *Channa punctatus*.[250] Effect on uptake of methylmercury by rainbow trout.[251] Inhibited respiration of loach (*Misgurnus fossilis*).[252] Inhibition of catalase, alone and in mixtures of metals.[78] 96-h LC50 for *Puntius conchonius* = 7.8 to 134 μg/L; biochemistry.[253] 96-h LC50 for fathead minnow = 168 μg/L; 0.26 μg/L reduced fecundity 46%; BCF = 4380 to 5680.[254] 240-h LC50 for *Puntius sophore* = 65 μg/L; histopathology.[255] 28-d LC50 for rainbow trout = 5 μg/L; mixtures with cadmium, copper, and selenium.[27] Concentrations in liver of *Hilsa ilisha*.[256] Uptake and physiological effects on five species.[257] Uptake by rainbow trout.[258] Uptake and effects of chelating agents on elimination by *Notopterus notopterus*.[129]
Mercury, methyl	Concentration, temperature, and oxygen consumption affected uptake by rainbow trout.[259] Effects of mercuric chloride, zinc, and temperature on uptake from water by rainbow trout.[251] Effects of ascorbic acid on acute toxicity and uptake by goldfish.[45] Effect on blood of bluegill.[260] Uptake by rainbow trout from food and effect on growth.[261] Uptake by rainbow trout.[258]
Mercury, phenyl	Uptake from water and food and depuration by guppy.[247]
Metasystox	5 mg/L decreased enzyme activity in *Channa striatus*.[262] 96-h LC50 for *Saccobranchus fossilis* = 15 mg/L.[23]
Methanol	14-d LC50 for guppy = 340 000 μmol/L.[2]
2-Methylnaphthalene	Uptake and depuration by coho salmon.[263]
N-Methyl-N-nitro-nitrosoquanidine	Produced mutants in bluegill cell cultures.[52]
Methyl parathion (Penncap-M)	12 mg/L decreased oxygen uptake by common carp.[264] 96-h LC50 for *Heteropneustes fossilis* = 7.0 mg/L.[22] 96-h LC50 for fathead minnow = 5.4 to 6.9 mg/L.[178]
Mirex	Altered bone development and metabolism in fathead minnow.[221] Induced mixed function oxidase in brook trout.[105]
Molinate	BCF with *Pseudorasbora parava* = 26.[55]
Molybdenum	28-d LC50 for rainbow trout = 790 μg/L.[27]
Monochloroamine	Affected rainbow trout erythrocytes.[265]
Monochlorobenzene	96-h LC50 for rainbow trout = 4.7 mg/L; 2 to 3 mg/L caused behavioral and biochemical changes.[266]
Monochrotophos	Effects on blood of *Heteropneustes fossilis*.[34]
Morpholine	96-h LC50 for zebrafish > 1000 mg/L; 48-h LC50 for golden orfe = 240 to 285 mg/L.[15]
Municipal wastewater	Caused physiological effects on rainbow trout.[267]
NTA (chelating agent)	Increased depuration of metals by *Notopterus notopterus*.[129]
Naphthalene	96-h LC50 = 1.6 mg/L for rainbow trout and 7.9 mg/L for fathead minnow; 0.85 mg/L decreased hatchability and growth.[51] Uptake and depuration by coho salmon.[263]
β-Naphthoflavin	Induced biochemical changes in common carp.[268]
1-Naphthol	LC50 for four species = 0.33 to 4.3 mg/L.[96]
Nickel	Avoidance threshold for rainbow trout = 23.9 μg/L.[134] Biochemical changes in rainbow trout after 6 months; mixtures with cadmium and chromium.[60] Effects on blood cells and eggs of three species.[132] Effects of copper and zinc on acute toxicity to guppy.[144] 48-h LC50 for *Channa punctatus* = 37 mg/L; mixture with zinc.[269] 48-h LC50 for *Pontius conchonius* = 158 to 586 mg/L; biochemistry.[270] 96-h LC50 for rainbow trout = 17.1 mg/L; effects of temperature, weight, and chlorine on acute toxicity.[110] 28-d LC50 for rainbow trout = 50 μg/L.[27]

Table 1—(Continued)

Pollutant	Type of Information
Nickel (Continued)	
	96-h LC50 for *Mystus vittatus* = 255 mg/L; mixtures with zinc and chromium.[128]
	Inhibition of catalase, alone and in mixtures of metals.[78]
	Concentrations in four German species.[86]
	Review of toxicity and bioaccumulation.[271]
	Uptake and effects of chelating agents on depuration by *Notopterus notopterus*.[129]
	Uptake and depuration by rainbow trout, alone and in mixtures with cadmium and chromium.[87]
Nitrite	
	Effects of pH and chloride on acute toxicity to bluegill.[108]
	Effect, with and without MS-222, on methemoglobin in channel catfish.[235]
	96-h LC50 for zebrafish = 620 mg/L; 48-h LC50 for golden orfe = 135 to 565 mg/L.[15]
4-Nitroaniline	
	96-h LC50 for zebrafish = 87.6 mg/L; 48-h LC50 for golden orfe = 35 mg/L.[15]
Nitrobenzene	
	96-h LC50 for zebrafish = 112.5 mg/L; 48-h LC50 for golden orfe = 60 to 89 mg/L.[15]
Octachlorostyrene	
	Did not induce mixed function oxidase in brook trout.[105]
Oil	
	Review of effects on fisheries.[272]
Oil shale retort water	
	Affected gills and growth of rainbow trout.[273]
Oil shale retort water, ammonia-stripped	
	Effects on rainbow trout and fathead minnow.[274]
Oil spill surfactant compounds	
	Effect on enzyme activity of rainbow trout.[275]
Oleometathion	
	LC50 = 58 µL/L for common carp and 48 µL/L for guppy.[112]
Organo-chemical effluent	
	Toxicity to fathead minnow reduced at least 92%.[276]
Organochlorines, total	
	Yearling coho salmon fed fish from the Great Lakes developed pathological conditions and accumulated organochlorines.[277]
Oxidiazon	
	May have strong persistence in common carp.[278]
Oxytetracycline	
	Uptake and depuration by rainbow trout.[279]
Ozone	
	Effects on striped bass eggs in fresh and salt water.[111]
PCBs	
	Common carp absorbed 67 to 93% from food.[280]
	Concentrations in four Canadian species.[40]
	Concentrations and abnormalities in wild striped bass.[6]
	Concentrations in various Finnish species.[106]
	Cooking reduced concentration in common carp fillets.[182]
PCBs (Continued)	
	Depuration by guppy and *Cichlasoma facetum*.[281]
	Effects on maturation of female *Oryzias latipes*.[282]
	Concentrations in various European species.[214]
	Concentrations in common carp from Lake Huron.[164]
	Size-specific mortality of lake trout fry.[165]
	Concentration in lake whitefish increased in two Great Lakes.[107]
PCBs (Aroclor 1254)	
	150 µg/kg caused physiological changes in coho salmon.[283]
	100 mg/L in food increased Cytochrome P-450 in rainbow trout.[156]
	Decreased disease mortality and affected blood of rainbow trout.[284]
	Increased formation of reactive metabolites of benzopyrene in rainbow trout.[285]
	Increased mixed function oxidase in brook trout.[286]
	Induced biochemical changes in common carp.[268]
	Relationship of concentrations in two Italian species to lipids, length, and concentration in water.[163]
	Increased sensitivity of rainbow trout to two chemicals but had no effect for seven other chemicals.[133]
	Uptake and depuration by young striped bass.[287]
	Uptake by young striped bass in Hudson Bay.[288]
	Uptake from food and enzyme induction in brook trout.[219]
	Uptake by and effect on growth of lake trout fry were affected by acetone.[11]
	Uptake and lethality in lake trout fry.[289]
PCBs (Aroclor 1260)	
	Relationship of concentrations in two Italian species to lipids, length, and concentration in water.[163]
PCBs (Aroclor 5460)	
	Induced mixed function oxidase in brook trout.[105]
PCBs (2,5-Dichlorobiphenyl)	
	Uptake from food and water and depuration by goldfish.[290]
PCBs (4,4'-Dichlorobiphenyl)	
	Accumulation and metabolism by common carp.[114]
PCBs (2,2', 5,5'-Tetrachlorobiphenyl)	
	Uptake from food and depuration by yellow perch.[291]
	Uptake from food and water and depuration by goldfish.[290]
PCBs (2,3', 4', 5-Tetrachlorobiphenyl)	
	Uptake from food and water and depuration by goldfish.[290]
PCBs (3,3',5,5'-Tetrachlorobiphenyl)	
	Uptake and metabolism by common carp.[114]
PCBs (2,2',5-Trichlorobiphenyl)	
	Uptake from food and water and depuration by goldfish.[290]
PCBs (2,4,5-Trichlorobiphenyl)	
	Uptake from food and water and depuration by goldfish.[290]
pH	
	Biochemical effects on whitefish (*Coregonus peled*) and brown trout.[292]
	96-h LC50 for desert pupfish (*Cyprinodon n. nevadensis*) = 4.56; pH = 7.00 reduced fecundity.[293]
	Low pH dissolved aluminum which was toxic to fish.[294]
	Low pH affected secretion of mucus by rainbow trout and ability of mucus to complex copper.[137]

(Table 1 Continued)

Table 1—(Continued)

Pollutant	Type of information
pH (Continued)	
	Bluegill avoided low pH.[295]
	Calcium increased survival of several species at low pH.[94]
	Estimated risk of acid rain to fisheries in Ontario.[296]
	Metals are a major cause of fish mortality in acidified lakes.[297]
	Physiological effects of low pH on rainbow trout.[298]
	Low pH reduced calcium in white sucker bones.[299]
	pH = 3 affected enzymes in lavaret (*Coregonus lavaretus*) and splake.[300]
	pH = 4 affected blood ion concentrations in rainbow trout.[301]
	pH = 4.3 to 4.8 caused several effects on rainbow trout.[302]
	Calcium increased survival of young brown trout at pH = 4.5.[92]
	pH = 5.3 inhibited reproduction of fathead minnow.[303]
	Effect of pH = 5.5 to 7.7 on acute lethality of vanadium to rainbow trout.[304]
	pH = 6.3 inhibited reproduction of desert pupfish.[305]
	pH = 9 caused metabolic acclimation of Mozambique tilapia.[306]
	Effect on uptake of sulfonamides by goldfish.[307]
Paper mill waste	
	Toxicity to fathead minnow reduced at least 92%.[276]
Paramar M50 (Ethyl parathion)	
	Inhibited ovarian activity of *Heteropneustes fossilis*.[20]
Parathion	
	Effects on liver enzymes in brown trout and common carp.[21]
	0.50 mg/L caused histological effects on brook trout.[308]
Pentachlorobenzene	
	Concentrations in lake and rainbow trout in Great Lakes.[113]
Pentachloronitrobenzene (PCNB, Quintozene)	
	Uptake and metabolism by golden orfe.[309]
	BCF with *Pseudorasbora parva* = 238.[55]
Pentachlorophenol (PCP)	
	113.1 μg/L decreased growth of fathead minnow.[184]
	96-h LC50 for zebrafish = 0.45 mg/L; 48-h LC50 for golden orfe = 0.40 mg/L.[15]
	96-h LC50 for guppy = 0.77 to 0.97 mg/L.[310]
	96-h LC50 for guppy = 0.16 to 3.42 μmol/L at pH 5 to 8.[115]
	Affected enzymes in *Notopterus notopterus*.[311]
	Effects of mixtures with phenol and 2,4-dinitrophenol on phosphatases of *Notopterus notopterus*.[190]
	Uptake by rainbow trout over 115 days.[312]
Permethrin	
	Caused histological changes in rainbow trout gills.[313]
Pesticide plant effluent	
	92% reduction in toxicity to fathead minnow.[276]
Phenol	
	Effects on behavior of guppy.[314]
	Effects of mixtures with 2,4-dinitrophenol and pentachlorophenol on phosphatases of *Notopterus notopterus*.[190]
	Rainbow trout avoided 3.2 to 6.5 mg/L.[315]
	0.01 mg/L depressed respiration of common carp.[316]
	96-h LC50 for guppy = 47.5 mg/L.[310]
	96-h LC50 for zebrafish = 27.8 mg/L; 48-h LC50 for golden orfe = 11.2 to 25 mg/L.[15]
	81.8 μg/L affected growth of fathead minnow.[184]
2-Phenoxyethanol	
	0.5 mL/L elevated plasma cortisol in rainbow trout.[237]
	LT50 for rainbow trout at 0.25 mL/L = 3.7 h.[317]
	Anesthetic effect on rainbow trout prolonged by increased carbohydrate.[37]
Phenthoate	
	BCF with *Pseudorasbora parva* = 36.[55]
Phenylxylylethanes	
	Uptake from food and enzyme induction in brook trout.[219]
Phosalone	
	96-h LC50 for *Saccobranchus fossilis* = 0.083 mg/L.[23]
Phosdrin 24EC (Mevinphos)	
	Acute toxicity to Czechoslovakian species.[56]
Phospharnidon (Dimecron)	
	Effects on blood of *Heteropneustes fossilis*.[34]
	96-h LC50 = 62 mg/L for *Anabas scandens* and 280 mg/L for *Heteropneustes fossilis*.[98]
Phosphoric acid triesters	
	Bioaccumulation and depuration by *Oryzias latipes*.[318]
Phosphorus	
	Possibly affected metabolism of embryos and larvae of loach.[252]
Pichloram	
	96-h LC50 for cutthroat trout = 4.5 mg/L.[161]
Pig manure	
	96-h LC50 for common carp = 0.55%; adverse effects when added to feed.[16]
Pindone	
	14-d LC50 for guppy = 11 μmol/L.[2]
Pluronic F-68	
	Increased time necessary for benzocaine and lidocaine to affect *Poecilia shenops*.[52]
Plutonium	
	Review of available bioaccumulation factors.[103]
	Concentrations in bluegill and largemouth bass.[28]
Polybrominated biphenyl ethers	
	Concentrations in five Swedish species.[319]
Polycyclic aromatic hydrocarbons	
	Caused histological changes in Amazon molly (*Poecilia formosa*).[320]
Potash	
	Effects on blood of *Heteropneustes fossilis*.[34]
Potassium	
	Concentrations in nine Canadian species.[91]
	Effects on blood of *Heteropneustes fossilis*.[34]
Pristane (2,6,10,14-Tetramethylpentadecane)	
	Accumulation and depuration by rainbow trout.[191]
Proclonol	
	14-d LC50 for guppy = 1.0 μmol/L.[2]

Table 1—(Continued)

Pollutant	Type of Information
Propoxur (Baygon)	96-h LC50 for *Heteropneustes fossilis* = 5.2 mg/L; effects on metabolism.[321] 96-h LC50 for *Heteropneustes fossilis* = 6.45 mg/L.[22]
Prothiophos	Uptake by guppy.[24]
Pulp mill effluent	80% reduction in 96-h LC50 for rainbow trout.[322] Treatment of effluent improved quality of downstream fish.[323]
Pyrethrin	44 g/ha reduced mosquitofish (*Gambusia affinis*) production by 37%.[324]
Pyridine	96-h LC50 for zebrafish > 512 mg/L; 48-h LC50 for golden orfe = 225 to >512 mg/L.[15]
Pyrrolizidine alkaloids	Effects on growth, mortality and histopathology of rainbow trout.[325]
Quinalphos (Ekalux)	0.25 mg/L decreased glucose absorption in *Channa punctatus*.[194] 96-h LC50 for *Saccobranchus fossilis* = 1.50 mg/L.[23] 48-h LC50 = 0.17 mg/L for *Aplocheilus lineatus* and 3.45 mg/L for *Macropodus cupanus*.[97]
Radium	Concentrations in nine Canadian species.[91] Review of available bioaccumulation factors.[103] Uptake and distribution in trout.[326]
Rotenone	Acute toxicity to rainbow trout was increased by PCBs.[133] 14-d LC50 for guppy = 0.14 µmol/L.[2]
Roundup (Glyphosate)	96-h LC50 for rainbow trout = 52 to 55 mg/L; lethal levels were avoided; field spraying caused no mortality.[327]
Ruthenium	Review of available bioaccumulation factors.[103]
Salicyclic aldehyde	96-h LC50 for zebrafish = 2.5 mg/L; 48-h LC50 for golden orfe = 3.1 to 4.1 mg/L.[15]
Salinity	Caused mass mortality of *Clarias gariepinus*.[328]
Selenium	Concentrations and abnormalities in wild striped bass.[8] Concentrations and histopathological changes in kidney of green sunfish (*Lepomis cyanellus*).[329] Review of toxicity and bioaccumulation.[330]
Selenium (IV)	Uptake from food and depuration by rainbow trout.[331] Uptake, distribution, and depuration by bluegill and largemouth bass.[332]
Selenium (VI)	28-d LC50 for rainbow trout = 5.17 mg/L; mixture with mercury.[27]
Wastewater	Effects on blood of *Heteropneustes fossilis*.[34]
Wastewater treatment plant effluent	Reduced numbers of downstream fish.[333] Affected behavior of fish in stream.[334] Altered enzyme activity in rainbow trout.[267]
Silver	96-h LC50 = 10.7 µg/L for fathead minnow and 9.2 µg/L for flagfish (*Jordanella floridae*).[335] 28-d LC50 for rainbow trout = 10 µg/L.[27]
Sodium bicarbonate	Effects on blood of *Heteropneustes fossilis*.[34]
Sodium dichloroisocyanurate	96-h LC50 for rainbow trout = 0.29 mg/L.[14]
Sodium dodecyl sulfate	BCF with common carp = 3.9 to 5.3.[191]
Sodium oxalate	96-h LC50 for zebrafish = 630 mg/L; 48-h LC50 for golden orfe = 160 to 325 mg/L.[15]
Sodium phosphate	Effects on blood of *Heteropneustes fossilis*.[34]
Sodium sulfate	Effects on blood of *Heteropneustes fossilis*.[34]
Strontium	28-d LC50 for rainbow trout = 250 µg/L.[27] Review of available bioaccumulation factors.[103]
Sulfonamides	Effect of pH on bioconcentration by goldfish.[307]
Sulphadimidine	Uptake and depuration by rainbow trout.[336]
Sulphobromophthalein	Half-life in rainbow trout was increased by carbohydrate.[37]
Supersaturation	Caused histopathological and hematological changes in *Clarius batrachus* and *Heteropneustes fossilis*.[337] Common carp and black bullhead (*Ictalurus melas*) from Columbia River were more resistant than those from Italy.[338]
Suspended solids (Turbidity)	Reduced growth of coho salmon.[339] Reduced respiration rate of striped bass.[340] Affected behavior of brook trout and creek chub (*Semotilus atromaculatus*).[341]
Synthetic fuel process wastes	Acute toxicity to fathead minnow.[342]
T-2 toxin	In feed caused physiological changes in rainbow trout.[343]
Tannic acid	400-mg/kg caused biochemical effects in *Clarius batrachus* and *Ophiocephalus punctatus*.[344]

(Table 1 Continued)

Table 1—(Continued)

Pollutant	Type of information
Tantalum	28-d LC50 for rainbow trout = 4.33 mg/L.[27]
Technetium	BCF = 11 with common carp and 75 with mosquitofish.[345]
Tellurium	28-d LC50 for rainbow trout = 21.6 mg/L.[27]
Temephos (Abate)	48-h LC50 = 1.24 mg/L for *Aplocheilus lineatus* and 11.4 mg/L for *Macropodus cupanus*.[208] Influenced fish movement in rivers.[346] 96-h LC50 for *Saccobranchus fossilis* = 207 mg/L.[23]
Temik (Aldicarb)	96-h LC50 for *Barbus conchonis* = 2.42 mg/L in hard water and 0.46 mg/L in soft water.[347]
Terbutryn	Uptake and depuration by rainbow trout tissue.[210]
Tetrachlorobenzenes	Concentrations in lake and rainbow trout in Great Lakes.[113]
Tetrachlorocatechol	96-h LC50 for rainbow trout = 1.5 mg/L.[181]
1,3,6,8-Tetrachlorodibenzo-p-dioxin	Concentration in *Zacco platypus* = 0.2 µg/kg.[348]
2,3,7,8-Tetrachlorodibenzo-p-dioxin	Concentrations in six Michigan species = 4 to 695 ng/kg.[349]
Tetrachloroethylene	96-h LC50 for rainbow trout = 4.99 mg/L; not affected by dimethylformamide.[180]
Thallium	28-d LC50 for rainbow trout = 180 µg/L.[27]
Thiobencarb (Benthiocarb)	BCF with mosquitofish = 14.[350] BCF with *Pseudorasbora parva* = 170.[55]
Thiodon	96-h LC50 for *Heteropneustes fossilis* = 0.0097 mg/L.[351] 96-h LC50 for *Saccobranchus fossilis* = 0.0108 mg/L.[23]
Thiometon	96-h LC50 for *Saccobranchus fossilis* = 11.8 mg/L.[33]
Thiosulphate	Reduced toxicity of copper to guppy.[130]
Thiotox	Effects on enzymes in *Mystus vittatus*.[101] 96-h LC50 for *Saccobranchus fossilis* = 0.0066 mg/L.[23]
Thorium	Concentrations in bluegill and largemouth bass.[28] Uptake and depuration by rainbow trout.[352]
Tin	28-d LC50 for rainbow trout = 420 µg/L.[27]
Tin, tributyl	1 µg/L induced organ changes in rainbow trout.[353] 30 µg/L affected *Rana temporaria* tadpoles.[354] 96-h LC50 for bluegill = 0.24 mg/L.[14]
Tin, triethyl	Inhibited hexokinase in trout and common carp.[355]
Titanium	28-d LC50 for rainbow trout = 7.31 mg/L.[27]
Toluene	96-h LC50 for fathead minnow embryos = 55 to 72 mg/L; 1-d-old = 25 to 36 mg/L; 30-d-old = 26 to 31 mg/L.[356] Uptake and depuration by coho salmon.[263]
Toxaphene	Mosquitofish from agricultural drainage were 30 times as tolerant as unexposed fish.[357] Recovery of a contaminated trout stream.[358] Effects on goldfish fin cells.[359] 100 ng/L decreased collagen and vertebral elasticity in channel catfish.[360]
Tributylphosphate	96-h LC50 = 9.6 mg/L for *Oryzias latipes* and 8.8 mg/L for goldfish.[361]
Trichloroacetic acid	2 g/L killed common carp fry in 29 days.[225]
1,2,4-Trichlorobenzene	Did not induce mixed oxidase in brook trout.[105] Concentrations in lake and rainbow trout in Great Lakes.[113]
3,4,5-Trichlorocatechol	96-h LC50 for rainbow trout = 1.0 to 1.5 mg/L.[181]
Trichloroethyl phosphate	96-h LC50 = 210 mg/L for *Oryzias latipes* and 90 mg/L for goldfish.[361]
2,4,6-Trichloro-p-nitrobiphenyl ether	120-h BCF with goldfish = 950.[183]
1,3,5-Trichloro-2-(4-nitrophenoxy)benzene	Concentration in *Zacco platypus* = 1.2 mg/kg[348]
2,4,5-Trichlorophenol	96-h LC50 for guppy = 5.0 to 15.5 µmol/L at pH 6 to 8.[115]
2,4,6-Trichlorophenol	Bioaccumulation by guppy.[362] 96-h LC50 for guppy = 3.1 to 39.8 µmol/L at pH 5 to 8.[115]
3-Trifluoromethyl-4-nitrophenol (TFM)	Acute toxicity to rainbow trout was not affected by PCBs.[133] Potential adverse and beneficial effects on lake trout.[49]
Trifluralin	BCF with *Pseudorasbora parva* = 3 142.[55] Effects in two model ecosystems.[363]
Trimethylphosphate	2 g/L caused pathological changes in guppy testes.[364]

Table 1—(Continued)

Pollutant	Type of information
Triphenyl phosphate	
	96-h LC50 = 1.2 mg/L for *Oryzias latipes* and 0.70 mg/L for goldfish.[361]
Tris(1,3-dichloroisopropyl)phosphate	
	96-h LC50 = 3.6 mg/L for *Oryzias latipes* and 5.1 mg/L for goldfish.[361]
Tritium	
	Review of available bioaccumulation factors.[103]
	Suppressed immune response of rainbow trout.[365]
Tryptophan	
	Not related to deformities in zebrafish.[47]
Tungsten	
	28-d LC50 for rainbow trout = 16.5 mg/L.[27]
Uranium	
	Concentrations in bluegill and largemouth bass.[28]
	Review of available bioaccumulation factors.[103]
	Uptake and depuration by rainbow trout.[362]
Urea	
	Effects on blood of *Heteropneustes fossilis*.[34]
Vanadium	
	Concentrations in five Canadian species.[40]
	Hardness and pH affected acute toxicity to rainbow trout.[305]
	Review of toxicity and bioaccumulation.[366]
	28-d LC50 for rainbow trout = 170 μg/L.[27]
	96-h LC50 for rainbow trout eyed eggs = 118 mg/L.[145]
Vegetable oil factory effluent	
	Physiological effects on *Channa punctatus*.[367]
X-rays	
	Broke chromosomes of *Tilapia mossambica*.[368]
3,5-Xylyl methylcarbamate	
	Uptake by guppy.[24]
Zinc	
	Accumulation from water and food and depuration by guppy.[59]
	Acute toxicity to and uptake by rainbow trout.[369]
	Concentrations in four British species.[62]
	Concentrations in two Welsh species.[138]
	Concentrations in two Hungarian species.[63]
	Concentrations in nine Canadian species.[91]
	Concentrations in live and dead *Scardinius erythrophtalmus*.[64]
	Concentrations in five Canadian species.[40]
	Critical literature review.[370]
	Effects on blood cells and eggs of three species.[132]
	Effects on blood of three species.[142]
	Effects of copper and mercury on acute toxicity to *Channa marulius*.[143]
	Effect on uptake of methylmercury by rainbow trout.[251]
	Effects of copper and nickel on acute toxicity to guppy.[144]
	Effects on rainbow trout of mixtures with copper in food.[139]
	Eliminated downstream fish.[371]
	Histopathological effects on *Puntius sophore*.[372]
	Inhibition of catalase, alone and in mixtures of metals.[78]
	MATC = 444 to 819 μg/L for steelhead trout (*Salmo gairdneri*); 144 μg/L increased ventilation rate.[373]
	Concentrations in Tennessee striped bass.[83]
	Concentrations in four German species.[86]
	Review of toxicity and bioaccumulation.[374]
	Uptake from food by common carp.[93]
	Effect of urban runoff on concentrations in three species.[89]
	5 mg/L decreased glycogen in *Anabas scandens*.[375]
	40 mg/L caused hemolysis in rainbow trout.[376]
	48-h LC50 for *Channa punctatus* = 31 mg/L; biochemistry; mixture with nickel.[269]
	96-h LC50 for *Channa punctatus* = 30 mg/L; histopathology.[377]
	96-h LC50 for chinook salmon = 84 μg/L; mixtures with cadmium and copper.[74]
	96-h LC50 for *Mystus vittatus* = 20.9 mg/L; mixtures with nickel and chromium.[128]
	28-d LC50 for rainbow trout = 1.12 mg/L.[27]
	14-d LC50 = 8.2 mg/L for channel catfish, 11.0 mg/L for bluegill, and 8.0 mg/L for largemouth bass.[378]
Zirconium	
	28-d LC50 for rainbow trout = 1.08 mg/L.[27]

[a] Species that are not identified are fish.
[b] LC50 = median lethal concentration.
[c] BCF = bioconcentration factor.
[d] IP = intraperitoneal injection.
[e] MATC = maximum acceptable toxicant concentration.

other pollutants on fish immune systems, Zeeman and Brindley[3] concluded that the fragmentary evidence available indicated that fish immune systems were usually suppressed by pollutants, but that evidence on formation of tumors was generally lacking.

The Missouri Department of Conservation investigated 74 fish kills in 1980 and determined that 39 of them were caused by pollution.[4] The California Water Resources Control Board published annual reports[5,6] on its toxic substances monitoring program, which analyzed fish and invertebrates from 28 streams for 9 metals and 55 synthetic organic compounds. Some of the reported concentrations exceeded recommended guidelines for protection of fish and wildlife. Among field studies, one indicated a relationship between pollution and skeletal deformities,[7] whereas another apparently did not.[8] In another field study, liver homogenates prepared from fish taken from the Rhine and Meuse Rivers activated indirect mutagens in river water, whereas homogenates from fish taken from a clean lake did not.[9]

A wide variety of other reviews and experimental results were published on the acute and chronic toxicity of pollutants to freshwater fish, although very few studies concerned toxicity to amphibians (Table 1). Uptake of pollutants from food and water and depuration also continued to be of great interest.

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